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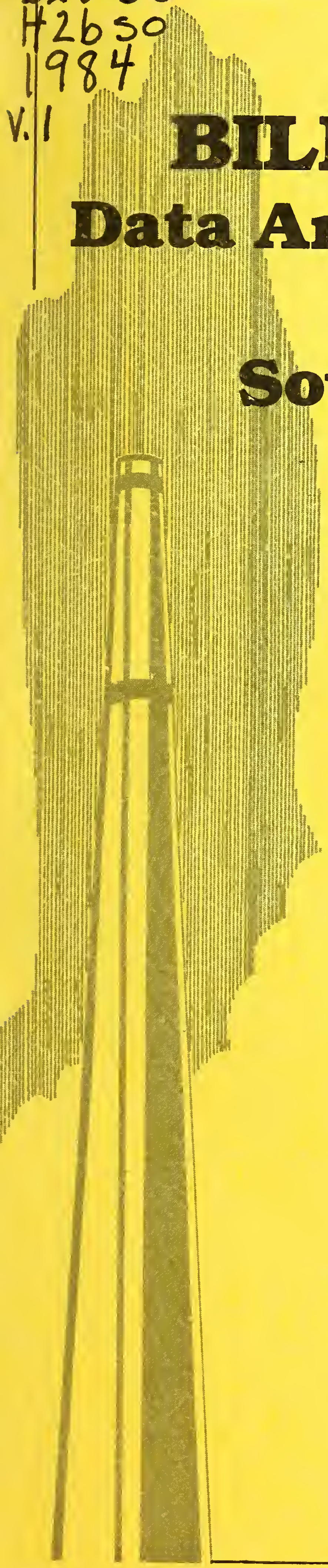

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BILLINGS SO_2 STUDY

Data Analysis, Model Validation
and
Source Determination

(DRAFT)

VOLUME I

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BY

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April, 1984

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PREFACE

This report is divided into three volumes for printing and distribution purposes. Volume I contains the text of the report. It includes narratives on data analysis, model validation and source determinations.

Volume II contains tables and figures that are referenced in the text. The lists of tables and figures are repeated in this volume for easy reference.

Volume III is an appendix to the text which contains a display of the air quality and meteorological data collected during the study year. Supportive material is also provided in this separate volume.

TABLE OF CONTENTS

Page

List of Tables iv

List of Figures viii

Abbreviations x

I. Introduction 1

II. Background 2

III. Study Year 3

IV. Four Study Months 4

V. Ambient Sulfur Dioxide Data Summary 5

VI. Diurnal SO_2 Plots 6

VII. Emissions from Industries 7

VIII. Stack Sampling by GCA 8

IX. Operation Schedule 9

X. Selection of Models 10

XI. Preprocessor Met Tape 11

XII. Statistical Analysis 15

XIII. Direction Analysis 16

XIV. Display of Air Quality and Meteorological Data 18

XV. Scenarios 20

XVI. Diurnal Trend Plots 23

XVII. Wind Roses 24

XVIII. Mass Emission Calculations 25

XIX. Modeling Results 26

XX. Source Contribution 33

XXI. Discussion 40

XXII. Summary and Conclusions 44

APPENDIX

LIST OF TABLES

1. List of Air Monitoring Sites

2. Maximum One Hour Concentrations - Summary - January, 1982
3. Maximum One Hour Concentrations - Summary - February, 1982
4. Maximum One Hour Concentrations - Summary - March, 1982
5. Maximum One Hour Concentrations - Summary - April, 1982
6. Maximum One Hour Concentrations - Summary - May, 1982
7. Maximum One Hour Concentrations - Summary - June, 1982
8. Maximum One Hour Concentrations - Summary - July, 1982
9. Maximum One Hour Concentrations - Summary - August, 1982
10. Maximum One Hour Concentrations - Summary - September, 1982
11. Maximum One Hour Concentrations - Summary - October, 1981
12. Maximum One Hour Concentrations - Summary - November, 1981
13. Maximum One Hour Concentrations - Summary - December, 1981

14. Twenty-Four Hour Concentrations - Summary - January, 1982
15. Twenty-Four Hour Concentrations - Summary - February, 1982
16. Twenty-Four Hour Concentrations - Summary - March, 1982
17. Twenty-Four Hour Concentrations - Summary - April, 1982
18. Twenty-Four Hour Concentrations - Summary - May, 1982
19. Twenty-Four Hour Concentrations - Summary - June, 1982
20. Twenty-Four Hour Concentrations - Summary - July, 1982
21. Twenty-Four Hour Concentrations - Summary - August, 1982
22. Twenty-Four Hour Concentrations - Summary - September, 1982
23. Twenty-Four Hour Concentrations - Summary - October, 1981
24. Twenty-Four Hour Concentrations - Summary - November, 1981
25. Twenty-Four Hour Concentrations - Summary - December 1981

26. Monthly Averages - October, 1981 to September, 1982

27. Annual Averages - October 1, 1981 to September 30, 1982

28. Emissions and Stack Data - Metric Units
29. Emissions and Stack Data - English Units

30. Operation Schedule - January, 1982
31. Operation Schedule - February, 1982
32. Operation Schedule - March, 1982
33. Operation Schedule - April, 1982
34. Operation Schedule - May, 1982
35. Operation Schedule - June, 1982
36. Operation Schedule - July, 1982
37. Operation Schedule - August, 1982
38. Operation Schedule - September, 1982
39. Operation Schedule - October, 1981
40. Operation Schedule - November, 1981
41. Operation Schedule - December, 1981

42. Operation Schedule -- October, 1981 through September, 1982

43. Monthly Wind Speed Averages

44. SO_2 - Means and Correlations Between Sites - January, 1982
45. SO_2 - Means and Correlations Between Sites - May, 1982
46. SO_2 - Means and Correlations Between Sites - August, 1982
47. SO_2 - Means and Correlations Between Sites - November, 1981

48. Direction Analysis Report -- Metra 061 - January, 1982
49. Direction Analysis Report -- Taft School 062 - January, 1982
50. Direction Analysis Report -- Shawnee 063 - January, 1982
51. Direction Analysis Report -- N. Johnson 064 - January, 1982
52. Direction Analysis Report -- Lockwood 065 - January, 1982
53. Direction Analysis Report -- Coburn 066 - January, 1982
54. Direction Analysis Report -- New Farm 014 - January, 1982
55. Direction Analysis Report -- Laurel BN 015 - January, 1982
56. Direction Analysis Report -- Taft School 062 - May, 1982
57. Direction Analysis Report -- Shawnee 063 - May, 1982
58. Direction Analysis Report -- N. Johnson 064 - May, 1982
59. Direction Analysis Report -- Lockwood 065 - May, 1982
60. Direction Analysis Report -- Coburn 066 - May, 1982
61. Direction Analysis Report -- New Farm 014 - May, 1982
62. Direction Analysis Report -- Laurel BN 015 - May, 1982
63. Direction Analysis Report -- Taft School 062 - August, 1982
64. Direction Analysis Report -- Shawnee 063 - August, 1982
65. Direction Analysis Report -- N. Johnson 064 - August, 1982
66. Direction Analysis Report -- Lockwood 065 - August, 1982
67. Direction Analysis Report -- Coburn 066 - August, 1982
68. Direction Analysis Report -- Laurel BN 015 - August, 1982
69. Direction Analysis Report -- Taft School 062 - November, 1981
70. Direction Analysis Report -- Shawnee 063 - November, 1981
71. Direction Analysis Report -- N. Johnson 064 - November, 1981
72. Direction Analysis Report -- Lockwood 065 - November, 1981
73. Direction Analysis Report -- Coburn 066 - November, 1981
74. Direction Analysis Report -- New Farm 014 - November, 1981
75. Direction Analysis Report -- Laurel BN 015 - November, 1981

76. Daily Scenario Tables - January 1-8, 1982
77. Daily Scenario Tables - January 9-16, 1982
78. Daily Scenario Tables - January 17-24, 1982
79. Daily Scenario Tables - January 25-31, 1982
80. Daily Scenario Tables - May 1-8, 1982
81. Daily Scenario Tables - May 9-16, 1982
82. Daily Scenario Tables - May 17-24, 1982
83. Daily Scenario Tables - May 25-31, 1982
84. Daily Scenario Tables - August 1-8, 1982
85. Daily Scenario Tables - August 9-16, 1982
86. Daily Scenario Tables - August 17-24, 1982
87. Daily Scenario Tables - August 25-31, 1982
88. Daily Scenario Tables - November 1-8, 1981
89. Daily Scenario Tables - November 9-16, 1981
90. Daily Scenario Tables - November 17-24, 1981
91. Daily Scenario Tables - November 25-30, 1981
92. Scenario Summary - January, 1982
93. Scenario Summary - May, 1982
94. Scenario Summary - August, 1982
95. Scenario Summary - November, 1981

96. Wind Rose Frequency Table -- Taft Composite - Annual -- October, 1981 to September, 1982
97. Wind Rose Frequency Table -- Taft Composite - First Quarter -- January, 1982 to March, 1982
98. Wind Rose Frequency Table -- Taft Composite - Second Quarter -- April, 1982 to June, 1982
99. Wind Rose Frequency Table -- Taft Composite - Third Quarter -- July, 1982 to September, 1982
100. Wind Rose Frequency Table -- Taft Composite - Fourth Quarter -- October, 1981 to December, 1981
101. Wind Rose Frequency Table -- Taft Composite - January, 1982
102. Wind Rose Frequency Table -- Taft Composite - February, 1982
103. Wind Rose Frequency Table -- Taft Composite - March, 1982
104. Wind Rose Frequency Table -- Taft Composite - April, 1982
105. Wind Rose Frequency Table -- Taft Composite - May, 1982
106. Wind Rose Frequency Table -- Taft Composite - June, 1982
107. Wind Rose Frequency Table -- Taft Composite - July, 1982
108. Wind Rose Frequency Table -- Taft Composite - August, 1982
109. Wind Rose Frequency Table -- Taft Composite - September, 1982
110. Wind Rose Frequency Table -- Taft Composite - October, 1981
111. Wind Rose Frequency Table -- Taft Composite - November, 1981
112. Wind Rose Frequency Table -- Taft Composite - December, 1981
113. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (1-300)
114. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (4-600)
115. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (7-900)
116. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (10-1200)
117. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (13-1500)
118. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (16-1800)
119. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (19-2100)
120. Wind Rose Frequency Table -- Taft Composite - January, 1982 - (22-1400)
121. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (1-300)
122. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (4-600)
123. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (7-900)
124. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (10-1200)
125. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (13-1500)
126. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (16-1800)
127. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (19-2100)
128. Wind Rose Frequency Table -- Taft Composite - May, 1982 - (22-1400)
129. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (1-300)
130. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (4-600)
131. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (7-900)
132. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (10-1200)
133. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (13-1500)
134. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (16-1800)
135. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (19-2100)
136. Wind Rose Frequency Table -- Taft Composite - August, 1982 - (22-1400)
137. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (1-300)
138. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (4-600)
139. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (7-900)
140. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (10-1200)
141. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (13-1500)
142. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (16-1800)
143. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (19-2100)
144. Wind Rose Frequency Table -- Taft Composite - November, 1981 - (22-1400)

145. Mass Emissions by Source -- Tons SO_2
146. Mass Emissions by Source -- Percent SO_2
147. Mass Emissions by Industry -- Tons SO_2
148. Mass Emissions by Industry -- Percent SO_2

149. Monthly Tons of SO_2 Emissions vs. Monthly SO_2 Averages

150. CHI-MAX, Effective Plume Rise & Rank - Model Output

151. Actual vs. Modeled Concentrations -- January, 1982
152. Actual vs. Modeled Concentrations -- May, 1982
153. Actual vs. Modeled Concentrations -- August, 1982
154. Actual vs. Modeled Concentrations -- November, 1981

155. Modeling Results for January, 1982 Using Complex II

156. Direction Analysis Summary -- Coburn Road

157. Direction Analysis -- SW Summary -- January, 1982
158. Direction Analysis -- SW Summary -- May, 1982
159. Direction Analysis -- SW Summary -- August, 1982
160. Direction Analysis -- SW Summary -- November, 1981

161. Direction Analysis Summary -- Laurel-BN

LIST OF FIGURES

1. Map of Billings

2. Map of Laurel

3. Diurnal SO_2 Plots -- Taft School 062 -- January, 1982
4. Diurnal SO_2 Plots -- N. Johnson 064 -- January, 1982
5. Diurnal SO_2 Plots -- Lockwood 065 -- January, 1982
6. Diurnal SO_2 Plots -- Coburn 066 -- January, 1982
7. Diurnal SO_2 Plots -- Laurel BN 015 -- January, 1982
8. Diurnal SO_2 Plots -- Taft School 062 -- May, 1982
9. Diurnal SO_2 Plots -- N. Johnson 064 -- May, 1982
10. Diurnal SO_2 Plots -- Lockwood 065 -- May, 1982
11. Diurnal SO_2 Plots -- Coburn 066 -- May, 1982
12. Diurnal SO_2 Plots -- Laurel BN 015 -- May, 1982
13. Diurnal SO_2 Plots -- Taft School 062 -- August, 1982
14. Diurnal SO_2 Plots -- N. Johnson 064 -- August, 1982
15. Diurnal SO_2 Plots -- Lockwood 065 -- August, 1982
16. Diurnal SO_2 Plots -- Coburn 066 -- August, 1982
17. Diurnal SO_2 Plots -- Laurel BN 015 -- August, 1982
18. Diurnal SO_2 Plots -- Taft School 062 -- November, 1981
19. Diurnal SO_2 Plots -- N. Johnson 064 -- November, 1981
20. Diurnal SO_2 Plots -- Lockwood 065 -- November, 1981
21. Diurnal SO_2 Plots -- Coburn 066 -- November, 1981
22. Diurnal SO_2 Plots -- Laurel BN 015 -- November, 1981

23. Profile of Stacks with Elevations

24. Input -- PRECRSTER
25. Output -- PRECRSTER
26. Input -- CRSMET
27. Output -- CRSMET
28. Output -- PRESTAT

29. Compass Directions with Wind Direction Limits

30. Diurnal Trend Plot -- Metra 061 -- January, 1982
31. Diurnal Trend Plot -- Taft School 062 -- January, 1982
32. Diurnal Trend Plot -- Shawnee 063 -- January, 1982
33. Diurnal Trend Plot -- N. Johnson 064 -- January, 1982
34. Diurnal Trend Plot -- Lockwood 065 -- January, 1982
35. Diurnal Trend Plot -- Coburn 066 -- January, 1982
36. Diurnal Trend Plot -- New Farm 014 -- January, 1982
37. Diurnal Trend Plot -- Laurel BN 015 -- January, 1982
38. Diurnal Trend Plot -- Taft School 062 -- May, 1982
39. Diurnal Trend Plot -- Shawnee 063 -- May, 1982
40. Diurnal Trend Plot -- N. Johnson 064 -- May, 1982
41. Diurnal Trend Plot -- Lockwood 065 -- May, 1982
42. Diurnal Trend Plot -- Coburn 066 -- May, 1982
43. Diurnal Trend Plot -- New Farm 014 -- May, 1982
44. Diurnal Trend Plot -- Laurel BN 015 -- May, 1982

45. Diurnal Trend Plot -- Taft School 062 -- August, 1982
46. Diurnal Trend Plot -- Shawnee 063 -- August, 1982
47. Diurnal Trend Plot -- N. Johnson 064 -- August, 1982
48. Diurnal Trend Plot -- Lockwood 065 -- August, 1982
49. Diurnal Trend Plot -- Coburn 066 -- August, 1982
50. Diurnal Trend Plot -- Laurel BN 015 -- August, 1982
51. Diurnal Trend Plot -- Taft School 062 -- November, 1981
52. Diurnal Trend Plot -- Shawnee 063 -- November, 1981
53. Diurnal Trend Plot -- N. Johnson 064 -- November, 1981
54. Diurnal Trend Plot -- Lockwood 065 -- November, 1981
55. Diurnal Trend Plot -- Coburn 066 -- November, 1981
56. Diurnal Trend Plot -- New Farm 014 -- November, 1981
57. Diurnal Trend Plot -- Laurel BN 015 -- November, 1981

58. Wind Rose -- Taft Composite -- Annual
59. Wind Rose -- Taft Composite -- Quarterly
60. Wind Rose -- Taft Composite -- Monthly (January - April)
61. Wind Rose -- Taft Composite -- Monthly (May - August)
62. Wind Rose -- Taft Composite -- Monthly (September - December)
63. Wind Rose -- Taft Composite -- Monthly (January, May, August, November)
64. Wind Rose -- Taft Composite -- Diurnal - January -- a.m.
65. Wind Rose -- Taft Composite -- Diurnal - January -- p.m.
66. Wind Rose -- Taft Composite -- Diurnal - May -- a.m.
67. Wind Rose -- Taft Composite -- Diurnal - May -- p.m.
68. Wind Rose -- Taft Composite -- Diurnal - August -- a.m.
69. Wind Rose -- Taft Composite -- Diurnal - August -- p.m.
70. Wind Rose -- Taft Composite -- Diurnal - November -- a.m.
71. Wind Rose -- Taft Composite -- Diurnal - November -- p.m.

72. Listing of Model Input Data -- January, 1982
73. Listing of Model Input Data -- May, 1982
74. Listing of Model Input Data -- August, 1982
75. Listing of Model Input Data -- November, 1981

76. Sequence of Valley Cross Sections Showing Inversion Breakup

ABBREVIATIONS

0800 061 -- (B061) -- Metra (Fairgrounds)
0080 062 -- (B062) -- Taft School
0080 063 -- (B063) -- Shawnee Park
0080 064 -- (B064) -- North Johnson
0080 065 -- (B065) -- Lockwood Park
0080 066 -- (B066) -- Coburn Road
0840 014 -- (L014) -- New Farm
0840 015 -- (L015) -- Laurel-BN
0070 062 -- -- Taft Composite

42401 -- Sulfur Dioxide - ppm
61101 -- Wind Speed - m/sec
61102 -- Wind Direction - Degrees
61103 -- Compass Wind Direction - Alpha
61106 -- Standard Deviation of Horizontal Wind Direction
62101 -- Temperatre - °C
61501 -- Stability -- Pasquill-Gifford
61401 -- Mixing Height - Meters

ppm -- Parts Per Million
ppb -- Parts Per Billion
ug/m^3 -- Micrograms per Cubic Meter

AQDHS -- Air Quality Data Handling System
EPA -- Environmental Protection Agency
JCL -- Job Control Language
Met -- Meteorology/Meteorological
NWS -- National Weather Service
SAROAD -- Storage and Retrieval of Aerometric Data
SO$_2$ -- Sulfur Dioxide
SPSS -- Statistical Package for the Social Sciences
UNAMAP -- User's Network for Applied Modeling of Air Pollution
USGS -- United States Geological Survey
UTM -- Universal Transverse Mercator

I. INTRODUCTION

This report has been prepared by the Montana Department of Health and Environmental Sciences for the six industries in Billings and Laurel (signees of the 1977 stipulation) and for the public at large.

The report presents an analysis of the Billings SO_2 and meteorological data collected from October, 1981 to September, 1982. A variety of means are used to undserstand the data and present it in summary and graphic fashions.

During the study period, the six industries supplied emission data to the Department. With this emission data combined with the air quality and meteorological data, the Department attempted to validate a dispersion model. This attempt proved unsuccessful. Consequently, the Department used direction analysis and mass emissions to show source contributions by the Billings and Laurel industries at receptors (monitors) in the area.

II. BACKGROUND

As a result of a 1977 agreement between the Montana Department of Health and Environmental Sciences and industries in Billings and Laurel, an air monitoring program was started in September, 1981. Monitoring was conducted at four SO_2 sites and one upper air site by Rockwell International from September, 1981 to September, 1982. The Department's Air Quality Bureau also monitored SO_2 at four other sites at the same time. Wind speed and direction data was also collected at the SO_2 sites. Table 1 lists the air monitoring sites and Figures 1 and 2 show their locations.

The industries that signed the stipulation (or agreement) include Montana Power (coal-fired power plant); Exxon, Conoco and Cenex (oil refineries); Great Western Sugar (sugar beet factory) and Montana Sulphur and Chemical (sulfur plant). Cenex is located in Laurel while the rest are in Billings. Figures 1 and 2 show the locations of the industries.

The stipulation stated that the monitoring was needed to determine air quality levels of SO_2 (to compare against standards). The stipulation also stated that the data collected (air quality and meteorological) would be used by the Department to validate a model and determine source contributions to the ambient levels.

During this period, the industries provided monthly reports of their emissions to the Department. Toward the end of the study some stack sampling was conducted by a contractor for EPA.

III. STUDY YEAR

Although data was collected from September, 1981 to September, 1982, this report only dealt with the time period from October 1, 1981 to September 30, 1982. Annual averages that have been calculated for this report reflect this time period.

The Department did use monthly emission data that was reported prior to October, 1981 to calculate average emissions.

IV. FOUR STUDY MONTHS

Due to the mass of data and the need to develop a pattern in the data, the Department decided to study four months in detail. They are:

a. January, 1982

b. May, 1982

c. August, 1982

d. November, 1981

The months were picked for seasonal patterns and data completeness.

V. AMBIENT SULFUR DIOXIDE DATA SUMMARY

The first approach to understanding the Billings SO_2 situation was to review and summarize the ambient data. The data is stored on the Department's Air Quality Data Handling System (AQDHS) and can be retrieved and printed out in detail lists. These lists have been provided to the industries and are not included in this report.

Several ambient data summaries were made from the detail lists for each of the eight monitoring sites. Tables 2 through 13 provide summaries for daily maximum one-hour readings. Tables 14 through 25 provide summaries of daily 24-hour average concentrations. Table 26 shows monthly SO_2 averages and Table 27 shows annual averages.

VI. DIURNAL SO_2 PLOTS

In order to visualize trends in the SO_2 data, the Department made diurnal SO_2 plots. Figures 3 through 22 show diurnal plots for most of the sites during the four study months. These plots show each individual reading, list the highest and second highest reading for each hour, and show the number of observations and the hourly average. The hourly averages are connected with a solid line to show the diurnal trend.

In general, many of the plots show higher concentrations during midday (6-1400 Hours). The readings also appear to be more scattered during this period. The Coburn Road site appears to stay elevated in early morning but then drops down in the afternoon. The patterns seem to be similar (albeit higher or lower) during different months.

VII. EMISSIONS FROM INDUSTRIES

Stack data and SO_2 emissions were supplied to the Department in the form of monthly reports. An agreement was made before the study for the industries to only report data for the second Tuesday of each month.

Much of the data was in forms that could not be used as direct input into a model. Most problems dealt with units and volume corrections. The Department made calculations to convert this data into a useable form.

Since the data varied from month to month, averages were made of SO_2 emissions, flow rates, and stack temperatures. It was felt that variations from month to month would be similar to variations from day to day and that the averages would probably be representative of the entire year.

Table 28 lists the average emissions, stack data, UTM coordinates, and elevations in metric units. Table 29 expresses the same information in English units. Figure 23 shows a profile of stacks and receptors with elevations.

VIII. STACK SAMPLING BY GCA

At the end of the SO_2 monitoring period, the EPA contracted with GCA to do stack sampling at Exxon, Conoco and Montana Sulphur. The tests were performed during October and November, 1982. The final reports were received by the Department in December, 1983.

It was hoped that this emission data could be tied with that from the monthly reports. However, after review by the Department, problems were found with the flow rates. Consequently, the stack tests could not be tied in with the monthly reports.

IX. OPERATION SCHEDULE

The Department compiled a listing of the operations of 21 sources (individual stacks) at the six industries in Billings and Laurel. Daily operation schedules are presented in Tables 30 through 41. Table 42 gives an annual summary.

The operation schedules were used in writing the scenarios, running the models and calculating mass emissions.

Montana Power and Great Western Sugar had on/off type operations, while the oil industries and Montana Sulphur ran fairly constantly all year.

X. SELECTION OF MODELS

Two models were selected to try to validate with the Billings SO_2 monitoring data. These were Complex I and Complex II.

Complex I and II are multiple point source models with terrain adjustments. They are sequential models utilizing hourly meteorological input (CRSMET or RAMMET type preprocessor data). Complex I assumes that hourly averaged plumes have a normal distribution in the vertical and a uniform distribution across a 22.5 degree sector (similar to the Valley model). Complex II assumes the plumes to have normal distribution in both the horizontal and vertical.

Complex I and II are the only models in the EPA UNAMAP series that handle complex terrain and take hourly sequential data. The Billings area is in complex terrain and receptors are located in elevated areas as well as the valley floor. It is possible to make a preprocessor tape (hourly sequential meteorological data) from the meteorological data collected at the Billings and Laruel air monitoring sites.

XI. PREPROCESSOR MET TAPE

A preprocessor met tape was made for input to the Complex I and II models. The customary method used by modelers is to obtain NWS surface observations and twice daily mixing heights for a whole year from the nearest weather station(s) and to process that data using the CRSMET program. Output from this program includes year, month, day, stability, wind speed, flow vector, temperature and mixing height.

The Department has a program similar to CRSMET called PRECRSTER. PRECRSTER uses site specific data in SAROAD format and makes a preprocessor met tape like CRSMET. PRECRSTER requires five parameters for input. These are: Wind speed, wind direction, temperature, stability and mixing height. Output from this program is the same as from CRSMET.

The modeling programs only allow one wind data set to be used. Since wind data was collected at eight sites, one site had to be chosen (or sites composited) to be representative of the valley. Before picking a site the Department decided to look at the data and see if any correlation existed between sites. Table 43 shows the average monthly wind speeds at the eight wind sites. Wind speeds at the Coburn Road and Laurel sites were faster than at the Billings/Lockwood valley floor sites.

The Department performed regressions of wind speeds between sites and regressions of wind directions between sites for two random months. The correlation coefficients for both wind speeds and wind directions were between .5 and .9. Two lobes were noted on the scattergrams for wind direction: One to the NE and the other to the SW. This shows up and down valley wind flow patterns. Wind directions between sites correlate better with faster winds (greater than 2.5 m/sec) than with slower winds (less than 2.5 m/sec). It was noted that wind speeds increase with increased elevation: Ridge sites have faster winds than valley floor sites.

Based on the above discussion, the Department decided that wind data from one site would be representative of the valley, especially if long term modeling was conducted or if several short term periods were averaged. The Department also decided to pick a valley floor site rather than a ridge site. It was felt that the wind profile exponents in the modeling programs would take care of the increase in wind speeds with increased elevation.

The Taft School wind site was picked as the representative valley floor site. However, as is the nature with any data collection, gaps exist in the data due to down time (repairs, calibrations, etc.). Since PRECRSTER requires a complete set of input data, it was necessary to fill in the data gaps based on a heirarchy of sites. The hierarchy is as follows:

a. Taft School - 062
b. Lockwood - 065
c. Metra - 061
d. Coburn - 066
e. Laurel BN - 015

Based on the above order, gaps were filled for wind speed, wind direction, and temperature. All wind speeds less than one m/sec were changed to one m/sec. (In modeling formulas, concentrations are proportional to the inverse of wind speed. If wind speeds are less than one m/sec or zero, the formulas calculate extremely high concentrations, or with zero, cause division problems.)

Two other parameters were needed for input to the preprocessor program. These were stability and mixing height. PRECRSTER requires stability to be entered in two hour intervals (12 per day) and mixing height in six hour intervals (four per day).

The modeling formulas require the input of the standard Pasquill-Gifford (PG) type stability (A through F). The Department reviewed the Rockwell reports and decided that the stability classifications reported could not be converted to a PG classification. Thus, an alternative approach was employed. The Department used the CRSMET program and Billings airport NWS surface observations for the study year to determine stabilities. The PG stabilities were taken off of the CRSMET output and put in SAROAD format for the PRECRSTER program. The PRECRSTER program only allows single increment steps of stability from hour to hour.

The Department obtained mixing height data at hours of 0000, 0600, 1200 and 1800 for each day of the study year from the acoustic sounder data presented in the Rockwell report. The heights were then put in SAROAD format and used in the PRECRSTER program. PRECRSTER reads the data in six hour intervals and interpolates for hours in between.

Rockwell presented two default values or height codes in their report. The value 888 meant unlimited mixing and 999 meant missing data. The Department filled in data gaps (999) by substituting a mixing height that occurred close to the hour that was missing, or using a mixing height that occurred at the same time on a day before or after (assuming similar meteorology). The unlimited value of 888 was kept at 888 meters. The Department felt that this mixing height would be high enough so as not to effect the plumes from Billings industries and so that hourly interpolations would be fairly realistic.

In review, the Department made data sets complete for one year for wind speed, wind direction, temperature, stability and mixing height. The program PRECRSTER processed the data sets and made a tape which is input to the models.

An example of input to PRECRSTER is shown in Figure 24 and output is shown in Figure 25. An example of input to CRSMET is shown in Figure 26 and output is shown in Figure 27.

XII. STATISTICAL ANALYSIS

In order to gain understanding of the Billings situation, the Department applied statistical analyses to the data base. The Department used the state's statistical package (SPSS) for this analysis. Before application of SPSS, the hourly records which are stored in horizontal rows (12 per line SAROAD format) had to be rearranged into vertical columns. The Department used a program called PRESTAT to do this.

Data sets were made for each of the four study months. Each data set had 36 variables by 744 or 720 hours in a month. The data sets contained a counter, Julian day, month and day, hour of day and then SO_2, wind speed, wind direction, and standard deviation of horizontal wind direction for each of the eight sites. Figure 28 gives an example of part of one data set. Using these data sets statistical analyses (regression, selection criteria, etc.) can be run.

Tables 44 to 47 show means and correlation coefficients comparing hourly SO_2 data between sites for the four study months. There appears to be some correlation between sites in the Lockwood area and between sites in Laurel.

SPSS and PRESTAT data sets were used to make data sets for input to the direction analysis program. Results of this are presented in the next section.

XIII. DIRECTION ANALYSIS

The direction analysis program (DIRECTAN) was set up by the Department to quantify and summarize SO_2 concentrations monitored at specific sites based on wind direction criteria. Input to the DIRECTAN program was based on selection criteria set up with SPSS and using the PRESTAT data sets.

An example of the selection criteria (in SPSS code) is as follows:

```
SELECT IF                  (B063WD GT 101.25 AND B063WD LT 123.75)
CONDESCRIPTIVE             B063S2 B063WS
```

This reads: If an hourly reading of wind direction from the Shawnee Park site (B063WD) is greater than 101.25 degrees and less than 123.75 degrees (or from the ESE compass direction), then condescript the Shawnee Park SO_2 readings (B063S2) and condescript the Shawnee Park wind speed readings (B063WS).

The above selection criteria was done in turn for each of the 16 compass directions (see Figure 29) and for each of the sites for the four study months. Condescript reports the mean, the number of valid observations and the number of missing observations for SO_2 and wind speed. This data was then input to the DIRECTAN program.

The DIRECTAN program displays the input data and makes calculations. Values that are calculated include percent wind direction, SO_2 strength factor and percent strength factor.

SO_2 strength factor is the mean of the SO_2 readings (from one of the 16 compass directions) times the percent wind direction. The strength factor gives a weighted SO_2 concentration. Percent strength factor is obtained by adding up individual strength factors and then dividing each by the total times 100.

The percent strength factors show the contribution from each compass direction on the total monthly average. Theoretically, the percents can be matched to the sources in those directions and source contribution shown.

Tables 48 to 75 show the direction analysis results for sites during the four study months. General comments are made in regard to the tables:

a. Sites in Laurel show two lobes: One from the SW and the other from the NE.

b. The Taft School and Coburn Road sites show two lobes: One from the SW and the other from the NE.

c. The Lockwood Park site shows two lobes: One from the north and the other from the SW. The lobe from the north does not occur too often but the results show high concentrations.

d. The sites to the east of Billings (Shawnee Park and North Johnson) show only one lobe from the SW.

e. SO_2 is seen coming from all directions at all sites. This might be attributed to calm conditions where direction has little meaning or due to inversion breakup times when SO_2 is trapped above at night and then is transported down when the sun begins to heat the ground (independent of wind direction).

XIV. DISPLAY OF AIR QUALITY AND METEOROLOGICAL DATA

In order to review the data, the Department made a display of the meteorological data with the ambient SO_2 data for each day of the study year. The Department thought that a display of this sort would allow a reviewer to look at a day's data and see if any trends existed (visual observation) and get an idea from where the SO_2 was coming.

The meteorological data that was used for this display came from the met data that was assembled for the preprocessor tape (see Section XI). The wind speeds that were less than one m/sec were kept as originally measured and not rounded up to one m/sec as was done for the preprocessor. In addition to the five parameters used for the preprocessor (wind speed, wind direction, temperature, stability and mixing height), standard deviation of horizontal wind direction and the alpha characters for the 16 compass directions were added to the display. As a naming convention, the Department refers to this met data set as Taft Composite.

The SO_2 data for each of the eight sites was retrieved from the Department's computer system and sorted by date, site and parameter with the met data. The display uses the Department's minimaster report format which presents labels, spreads out the SAROAD record, and inserts a decimal for ease of reading.

Highlights were added by hand. Brackets were added around each site's 24 hour readings. A number was added to the left of the brackets which gives the 24-hour average in parts per billion. The maximum one-hour readings are underlined for each site.

The displays for the whole study year are presented in the appendix. The year for October, November and December is 1981 rather than 1982 as is shown.

The Department reviewed four months of the displays and presented the results in the form of daily scenarios. Results are presented in the next section.

XV. SCENARIOS

The display of met and ambient SO_2 data was set up so that the Department could visually look at the data and write a brief scenario of what was occurring for each day of the four study months. A check sheet was set up to note meteorology, Billings area SO_2 trends, Laurel area SO_2 trends, operation schedules and comments.

For SO_2 concentration trends, the Department noted hours of similar elevated readings or peaks that stood out over a background level or baseline. For the same time period, the Department noted the corresponding meteorology and the subareas or sources that caused or contributed to the concentrations. There was no attempt to note how strong the elevated readings were, but just their occurrence.

The letters that were used for the subareas are as follows:

A - Cenex

B - Montana Power, Conoco and Great Western

C - Exxon, Montana Sulphur

Tables 76 to 91 give the daily scenarios for the four study months. Tables 92 to 95 summarize some of the comments from the daily scenarios.

The following points are made:

1. Inversion breakup and buildups during calm periods are major factors that cause elevated SO_2 readings to occur at the Billings monitors. Breakups cause elevated readings to occur in the early morning to mid-day (6-1400 hours).

2. SO_2 can be seen going from Billings industries to Laurel monitors and from Laurel industries to Billings monitors. In the scenario summaries, there are more days noted when SO_2 traveled from Billings to Laurel. This

does not mean that the phenomenon happens more than the reverse but that it was easier to note.

3. During calm periods and high mixing heights (300-400 meters), SO_2 from the stacks rises and buildups occur aloft. During this time concentrations are not seen at the valley floor monitoring sites, but can be seen at the higher Coburn Road site.

4. During calm periods and low mixing heights (30-200 meters), SO_2 from the stacks is not allowed to rise too far. Buildups can occur at ground level where the monitors are located.

5. Faster wind speeds (greater than 2-3 m/sec) cause the plumes from the industrial sources to impact on the ground. A combination of faster winds dominating plume rise and blowing the plumes parallel to the ground and terrain effects (causing downwash) may be the reason why the plumes are coming down.

6. When there are faster wind speeds, the wind direction data becomes more reliable. By having more confidence in the wind direction data, it is easier to tell from which subarea or source the SO_2 was coming.

7. When there are slower winds, the wind direction data became less reliable and consequently it became harder to tell from which subarea or source the SO_2 was coming.

8. Inversion breakups and faster winds bring the plumes down and can occur at the same time and have an additive effect. For example, buildup can occur at night and, in the morning, inversion breakup can occur. At the same time in the morning the wind speeds start to pick up and bring the "just emitted" SO_2 to the ground. Together the old emissions that were build up at night add up with the new emissions during the day and cause higher concentrations at a site.

9. Each of the subareas can have an additive effect on each other as the wind flows either up or down the valley. For example with a SW wind, SO_2 emitted from subarea A can first be seen at the Laurel-BN site. Then the SO_2 travels on to Billings where it adds up with emissions from subarea B and together they impact the Coburn Road and Lockwood sites. Then the SO_2 from subareas A and B add up with emissions from subarea C and are seen at the North Johnson and Shawnee Park sites.

The reverse can also be seen: SO_2 from subarea C can be emitted with a NE wind and is measured at the Coburn Road site. Then the SO_2 adds up with emissions from subarea B and both go on to Laurel where they are monitored at the Laurel-BN and New Farm sites. It would be assumed that SW of Laurel, subareas C and B would add up with emissions from A, however, no monitor exists.

XVI. DIURNAL TREND PLOTS

In order to gain more understanding into the diurnal trends in Billings, the Department made diurnal plots of SO_2, wind speed and standard deviation of horizontal wind direction for each site for the four study months.

Figures 30 to 57 show these plots.

It is interesting to note that the traces for SO_2 and wind speed follow each other. In fact, the wind speed actually lags a little behind the SO_2 trace. This means that there is another factor that causes each to go up. This can be attributed to the heating of the ground by the sun. The sun comes up and heats the ground which causes breakup and increased wind speeds. In general, sunrise corresponds to the time of breakup.

When the sun sets, wind speeds die down and concentrations go down. Buildups then occur later (20-2400 hours) either aloft or near the ground.

XVII. WIND ROSES

The Department made a series of wind rose plots using the Taft Composite wind data set. These wind roses are an aid in understanding wind flow patterns in Billings and along the Yellowstone River valley.

Figure 58 gives a wind rose for the whole study year. Figure 59 gives quarterly wind roses. Figures 60 to 62 give monthly wind roses. Figure 63 gives monthly wind roses for each of the four study months. Figures 64 to 71 give diurnal wind roses for the four study months. Tables 96 to 144 give the wind rose frequencies for each of the wind roses.

A few comments are made concerning the diurnal wind roses. In the early morning, the winds are mostly the slow river drainage southwest types. In the afternoons the wind directions often change and the speeds pick up. Then in late evening the winds die down again and follow the river drainage.

The monthly, quarterly and annual wind roses all show similar patterns. There are essentially two nodes: One from the SW and the other from the NE. The node from the SW occurs about twice as often as the node from the NE.

Winds from the SE show low wind speeds and reflect calm, variable conditions. Winds from the NW usually show fast wind speeds and are probably caused by frontal passages.

XVIII. MASS EMISSION CALCULATIONS

Mass emissions (tons/month or tons/year) are calculated by multiplying an emission rate (g/sec) times an operation period (days/month or days/year) and using appropriate conversion factors. Total mass emissions in an area (Billings or Laurel) can be found by adding up the individual mass emissions. Percents can be found by dividing the individual emissions by the total times 100.

The emission rates were presented in Section VII and the operation periods were presented in Section IX.

Tables 145 and 146 give mass emissions by ton and percent for each source. Tables 147 and 148 give mass emissions by ton and percent for each industry. Emissions from sources in Billings and Laurel were kept separate for totaling purposes.

Table 149 presents the results of a regression that was done between the monthly mass emissions from the Billings sources and the monthly SO_2 averages for each of the eight monitoring sites. This table shows correlation coefficients between .6 and .9 when all twelve months are present. Although the results show good correlation between emissions and ambient concentrations (over a long term period), it shouldn't necessarily be assumed that mass emission is the only factor effecting concentrations (especially for short term concentrations).

The effects that meteorology and terrain cause on the dispersion of plumes and the relative positions of the monitors with respect to the industries also play important roles on the concentrations that are seen at the monitors (both for the long term and for the short term).

Mass emission calculations can (in a rough manner) be used to approximate source contribution.

XIX. MODELING RESULTS

As mentioned, the intent of this report was to validate a model(s) and to show source contribution by several Billings and Laurel industries at receptors in the area. This section shows what was done to set up and run the models (options and input data) and what resulted as the programmed output. Discussions will center around what was done to validate the model(s) and why they failed to match up with the ambient data collected at the monitoring sites.

In review, the Department chose the Complex I and II models because of Billings' complex terrain and set up a representative preprocessor met tape which would be input to the models. The Department used stack emissions that were supplied to it by the industries and located UTM coordinates and elevations for the receptors and sources on USGS maps (see Table 28). The operation schedule presented the Department with the knowledge of which sources ran on which days.

The four study months were selected to be modeled. The Complex I and II models were run on identical input data and the results of both were compared with the actual ambient data as well as each other.

It was desirable to run the models for one month at a time using the same set of stack information for the whole month. However, since some sources ran less than a full month, rounding was done either up to the full number of days in the month or down to zero days. The following was done:

a. For January, the Exxon Cat unit and the Cenex #3 Boiler were rounded up to 31 days.

b. For May, the Exxon Cat unit was rounded to zero days. Cenex's sources were rounded to 31 days.

c. For August, the Montana Power Corette plant was rounded to zero days. Cenex's sources were rounded to 31 days.

d. For November, no changes were made. All sources were 30 days.

In addition to the point source information, the Department selected several options and parameters for input to the models. These included: Starting Julian day, starting hour, number of averaging periods, number of hours in an averaging period, technical and control options, and wind and terrain factors.

The starting Julian days for each month were as follows:

a.	January	1
b.	May	121
c.	August	213
d.	November	305

The starting hour for each month was set at one; the number of averaging periods corresponded to the number of days in the month (30 or 31); and the number of hours in an averaging period was set at 24. (The above allowed the models to calculate twenty-four hour concentrations for each site for each day of the four study months.)

The Department also ran the Complex II model to calculate a monthly average for January and to show modeled source contribution. For this, the starting Julian day was one, the starting hour was one, the number of averaging periods was one, and the number of hours in an averaging period was 744.

The technical and control options included the following:

IOPT(1)=1	Use terrain adjustments
IOPT(2)=1	Do not include stack downwash calculations
IOPT(3)=1	Do not include gradual plume rise calculations
IOPT(4)=1	Include buoyancy induced dispersion

IOPT(17)=0	Provide averaging-period contributions
IOPT(18)=0	Provide averaging period summary
IOPT(24)=1	Punch averaging period concentrations on cards (disk)
IOPT(25)=1	Use complex terrain option

IOPT(24)=1 allowed averaging period concentrations to be written to disk in an eighty character card format. The actual twenty-four hour concentrations were then laid over (or next to) the modeled concentrations. The new data set was then used in SPSS to run regressions of actual versus modeled concentrations.

Wind and terrain factors were selected for input to the models. The Department chose wind profile power law exponents that reflected the higher wind speeds that were seen at the Coburn Road site versus what was seen at the valley floor sites. The wind profile exponents that were input to the models were as follows: .1, .1, .1, .1., .1, .1 for each of the stabilities (A through F).

The terrain adjustment factors selected for the models were the EPA default values. These were as follows: .5, .5, .5, .5, .0, .0 for each of the stabilities (A through F).

Figures 72 to 75 show the input data sets that were used to model the point sources for the four study months. The figures also show the associated JCL (Job Control Language) that goes along with running the models.

The models were run on the State's IBM 3033N computer and the results consisted of printed output and disk data sets containing the averaging period concentrations for each site and for each day of the four study months.

The printed output consists of summary and descriptive information (mandatory output) as well as the averaging period contributions and the averaging period summary. The mandatory output consists of the following: General input, point source data, significant point source ranking, receptor data and additional information.

Information is provided in the mandatory output which helps to focus in on how the models handle (and apportion) the various point sources. Table 150 shows the significant point source ranking, chi-max and the effective height. Chi-max is the maximum expected ground-level impact under B stability with a stack top wind speed of 3 m/sec. The significant point source ranking is based on chi-max. The effective height is the sum of the stack height plus plume rise (based on Briggs plume rise formulas). Generally, sources that show a large chi-max (low ranking number) are usually the ones that the models say are the major contributors. Sources with large effective heights are usually not major sources (as treated by the models) because the plumes are allowed to go up and disperse into the atmosphere. Later discussions will focus on this information.

The averaging period summary and the concentrations written to disk (IOPT(24)=1, one data set each for Complex I and II) gave the modeled twenty-four hour concentrations for each site for each day. Using a computer overlay function and the IOPT(24) data sets, new data sets were made (one for each of the study months) that contained the Julian day, actual concentration, Complex I modeled concentration, Complex II modeled concentration, and site.

Using the above new data sets and SPSS, regressions were made between the actual and modeled concentrations. Tables 151 to 154 show the means, number of pairs and the correlation coefficients for all data and for each site. Generally the models underpredicted (compared to actual concentrations) and the correlations were poor.

The printed output also gives the averaging period contributions. The averaging period contributions show the micrograms per cubic meter that each point source contributes to the total averaging period. When the averaging period is twenty-four hours, the output gives averaging period contributions for each day and site. However, it is impractical to summarize so many averaging period contributions. (There are 21 sources x 123 days x 8 sites = 20664 daily source contributions.)

Consequently, for demonstration purposes, the Department ran the Complex II model on a monthly basis (mentioned before). Table 155 shows monthly modeled and actual averages and the percent contributions from the sources for the month of January.

The percent contributions in Table 155 are not realistic. According to the model, the Montana Sulphur stack seems to be the major source in Billings. In Laurel, the major source appears to be the Cenex sulfur plant. Also, there appears to be hardly any contribution by the Montana Power Corette plant. (This seems unrealistic since the Department has seen plume impact by this source during January at Coburn Road and other sites.) The percent contributions for the monthly averaging period are similar to those seen for the shorter twenty-four hour averaging periods. The Department concludes that the modeled percent contributions can not be used for source apportionment.

The Department tried to understand why the models (as used) were unable to match up with the actual concentrations. A number of parameters were looked at which effect modeled concentrations and also how they effect or coincide with concentrations that are seen in the field. They are as follows: Effective plume rise, wind speed, fumigation, and receptor location.

The effective plume rise is calculated in the models using the Briggs plume rise formulas. For example, the model calculates an effective plume height of 485 meters for the Montana Power Corette plant (stack height plus plume rise). In reality, the plume might rise from 30 to 60 meters above stack height (or have an effective plume height of 140 to 170 meters). The other sources in Billings and Laurel may show patterns similar to the Montana Power Corette plant: Actual plume rise is less than calculated by the models (Briggs formulas). The effect that the plume rise has on modeled concentrations is that sources with large plume rises are allowed to go up higher and disperse (and do not contribute to modeled concentrations at the receptors).

In modeling formulas, concentrations are inversely proportional to wind speed. The logic being: The faster the wind blows, the more mixing and dispersion takes place and lower concentrations are seen at the receptors. However, in Billings quite different situations take place. With calm winds, the emissions from the stacks rise and concentrations are not seen at the receptors (unless concentrations build up over the whole valley with a low mixing height and then they are seen at the receptors).

With faster wind speeds (greater than 2-3 m/sec), the plumes from the sources come down and impact the receptors (direction dependent). This was observed by looking at the met and ambient data for the scenarios.

Another case exists with faster wind speeds. When inversion breakup occurs (due to ground heating) and concentrations increase, wind speeds increase simultaneously (due to the same ground heating). The net effect being: No relationship between SO_2 concentrations and wind speeds occur as far as modeling is concerned.

Another reason why the models are unable to predict accurate concentrations in Billings is because of their inability to handle fumigations or inversion breakups. The following quote from the MPTER User Guide discusses this problem:

> "MPTER (Complex I and II) does not include calculations for the transitional phenomenon of fumigation, which is the elimination of an inversion layer containing a stabilized plume from below (which causes

> mixing of pollutants downward, resulting in uniform concentrations with height beneath the original plume centerline)."

As a result, the models do not have any memory of what has been emitted and built up at night and then allowed to come down and disperse at midday.

The locations of the receptors with respect to the sources may also be a reason why the models do not accurately predict concentrations. The receptors are fairly close to the sources and the model's source-receptor relationship is highly dependent on wind direction. If the wind directions are not right on the line from the sources to the receptors, then the receptors may not be "seeing" the plumes from the sources. The diffusion coefficients (sigma y and sigma z) are supposed to handle some of this fanning, but may not be large enough to account for what is seen in Billings.

The Department did try to validate a model so that the results compared better with the actual concentrations. This involved changing some of the input parameter for the sources. For instance, since effective plume height seemed too high, the Department lowered stack exit temperatures to 293°K so that no plume rise occurred. In some cases, the physical stack heights were also lowered. The Department also raised emission rates at Montana Power and Exxon to reflect a balance of concentrations seen from those directions. The regressions (comparing actual to modeled concentrations) improved slightly but the juggling of figures seemed inappropriate.

The Department concludes that Complex I and II are not able to model sources in Billings with its complex terrain and meteorological features. This conclusion also applies to any Gaussian dispersion model.

XX. SOURCE CONTRIBUTION

This section is intended to show how the Department calculated source contribution by the Billings and Laurel industries on the annual average SO_2 concentrations at Coburn Road and Laurel-BN sites during the study year.

In order to determine source contribution from the six industries on the annual average at Coburn Road, a couple of procedures were applied. First, in order to get an idea of the magnitude of each source, the Department calculated percentages based on mass emissions. (It is noted that this procedure considers no knowledge of meteorology, dispersion and location of receptors with respect to the location of the sources and assumes that the concentrations are directly proportional to emissions.) The percentages listed on Table 148 for the five Billings industries were used for this determination. In order to figure in the contribution by Cenex, the Department arbitrarily assigned that plant a five percent contribution. The Billings plants were then multiplied by 95 percent (or 0.95). The results of this determination are shown below:

MPC = 95 X 26.7 / 100 = 25.3%
CON = 95 X 17.6 / 100 = 16.7
GTW = 95 X 2.7 / 100 = 2.5
EXX = 95 X 40.4 / 100 = 38.2
MTS = 95 X 12.3 / 100 = 11.6
CEN = 5 X 100.0 / 100 = 5.0
99.3%

A second procedure was also used to calculate source contribution on Coburn Road. This procedure used the direction analysis results to proportion out subareas (A, B and C) and then used mass emissions to proportion out individual sources within those subareas.

This second procedure followed some individual steps. The first step is to add up the percent strength factors for the SW directions and for the NE directions. Table 156 shows the summaries of the four study months. The percent strength factors from the SW direction show the contribution from subareas A and B while the percent strength factors from the NE directions show the contribution from subarea C.

The next step is to average the SW percent strength factors and to average the NE percent strength factors for the four study months. The Department assumes that the averages of the four study months are representative of the annual average. A summary of this averaging is as follows:

	SW	NE	SW + NE
January	56.7%	38.7%	95.4%
May	51.0	33.4	84.4
August	34.6	48.9	83.5
November	81.4	9.7	91.1
Average	55.9	32.6	88.5

The average percent strength factors for the SW directions equaled 55.9% and the average for the NE direction equaled 32.6%. The total of the two equaled 88.5% or explained approximately 90% of the SO_2 seen at the Coburn Road site.

The third step is to set up a ratio and equate it with the sources in those areas. The ratio and the equation is as follows:

$$\frac{SW}{NE} = \frac{55.9}{32.6} = 1.71 = \frac{A + B}{C} \qquad (1)$$

The fourth step is to equate the sum of SO_2 from each of the subareas with total annual average at Coburn Road. This is as follows:

$$A + B + C = .029 \text{ ppm} \qquad (2)$$

A situation presents itself by having two formulas and three unknowns: If one of the unknowns can be determined independently of the others and substituted into equations (1) and (2) above, then the other two values can be solved using simultaneous equations. This leads to the next step.

The fifth step is to solve for A: The amount or fraction of SO_2 from subarea A (The Laurel Cenex plant) that contributes to the annual average at Coburn Road for this study year. This is done by making two assumptions. These are as follows:

1. All of the SO_2 from the SW sector at Taft School is from subarea A.
2. The amount of SO_2 at Taft School from subarea A is equal to the amount of SO_2 at Coburn Road from subarea A.

The fraction of SO_2 from subarea A at Taft School is found by adding up the percent strength factors from the SW directions. The concentration value for the SW sector is found by multiplying the sum of the percent strength factors by the monthly average. This value is divided by the monthly average at Coburn to show percent contribution from subarea A at that site. The figures for the four study months are averaged to give approximate annual averages. Tables 157 to 160 show these results and a brief summary is presented below:

	Taft SW Percent Strength Factor	Taft Monthly Average	Taft SW Concentration	Percent Taft (SW)/ Coburn (total)
January	20.5%	21.8 ppb	4.4 ppb	8.6%
May	16.2	6.1	1.0	15.6
August	29.2	12.4	3.6	13.0
November	56.5	12.2	6.9	12.8
Average	30.6	13.1	4.0	12.5

From this step it is concluded that the value for A (the amount of SO_2 from

Laurel at Coburn Road) is equal to .004 ppm (or 4 ppb). This step also shows that 12.5% of the SO_2 at Coburn Road is from the Cenex plant.

With A = .004, equations (1) and (2) reduce to the following:

$$1.71 = \frac{.004 + B}{C}$$

and

$$.004 + B + C = .029$$

Solving the two equations simultaneously gives B = .0143 or approximately .014 and C = .0107 or approximately .011. In summary, the contributions from the three subareas are as follows:

A = .004

B = .014

C = .011

The sixth and final step is to use the partial contributions by subarea and the mass emissions presented on Table 147 to calculate source contribution. The results are as follows:

MPC = .014 X (5460/9626) / 100 = .00794 = 27.4%

CON = .014 X (3603/9626) / 100 = .00523 = 18.0

GTW = .014 X (563/9626) / 100 = .00081 = 2.8

EXX = .011 X (8269/10796) / 100 = .00842 = 29.0

MTS = .011 X (2527/10796) / 100 = .00257 = 8.8

CEN = .004 X (8794/8794) / 100 = $\underline{.00400}$ = $\underline{13.8}$

.02897 99.8

The following table presents the results of the two estimation methods. Since there is a degree of uncertainty in the determinations, the Department shows a range of values in which the actual source contributions would probably occur. The table also presents single percent numbers that can be understood as the Department's best estimate of the concentrations by the six industries on the annual average at Coburn Road during the study year.

	Estimation Method 1	Estimation Method 2	Range	Best Estimate
Montana Power	25.3%	27.4%	25-33%	31%
Conoco	16.7	18.0	13-19	14
Great Western	2.5	2.8	2-4	3
Exxon	38.2	29.0	26-34	30
Montana Sulphur	11.6	8.8	8-12	10
Cenex	5.0	13.8	10-14	12
	99.3	99.8	84-116	100

The Department also wished to calculate the source contributions on the Laurel-BN site in Laurel. This was done by a method similar to what was used for the Coburn Road site.

The first step is to add up the percent strength factors for the SW directions and for the NE directions for each of the four study months. The percent strength factors from the SW directions show the contribution from subarea A while the percent strength factors from the NE directions show the contribution from subareas B and C. Table 161 shows these results.

The second step is to average the SW percent strength factors and to average the NE percent strength factors. The Department assumed that the average of the four study months are representative of the whole study year. A summary is presented as follows:

	SW	NE	SW + NE
January	58.3%	38.1%	96.4%
May	65.5	21.3	86.8
August	59.8	19.2	79.0
November	81.7	9.6	91.3
	66.3	22.0	88.3

The average percent strength factors for the SW directions equaled 66.3% and the average for the NE directions equaled 22.0%. The total of the two gave 88.3% or explained approximately 90% of the SO_2 seen at the Laurel-BN site.

For the third step, the Department assumed that all of the SO_2 from the NE direction came from the Billings industries (or 22% of the annual average at Laurel-BN site). By using the 22% figure, the sources in Billings can be proportioned by mass emissions or using percentages presented in Table 148. The following summarizes these results.

MPC = 22 x 26.7 / 100 = 5.8%

CON = 22 x 17.6 / 100 = 3.8

GTW = 22 x 2.7 / 100 = 0.6

EXX = 22 x 40.4 / 100 = 8.9

MTS = 22 x 12.3 / 100 = 2.7

CEN = 78 x 100.0 / 100 = 78.0

99.8

Since there is a degree of uncertainty in the determinations, the Department figured a range of values in which the actual source contribution would probably occur. The following table shows this range and the Department's best estimate of the contributions by the six industries on the annual average at the Laurel-BN site during the study year.

	Estimation Method	Range	Best Estimate
Montana Power	5.8%	5-9%	6%
Conoco	3.8	3-7	4
Great Western	0.6	0-3	1
Exxon	8.9	8-12	9
Montana Sulphur	2.7	2-6	3
Cenex	78.0	70-80	77
	99.8	88-117	100

XXI. DISCUSSION

The purpose of this section is to briefly discuss some of the aspects of the report and to emphasize some points that the Department feels are important to the final determination.

The objectives of the stipulation were to (1) determine air quality SO_2 levels, (2) validate a model and (3) use the data and model to determine source contributions.

The air quality levels during this study period showed that there were no violations of any Federal SO_2 standards. However, there were violations of the Montana 24-hour and annual SO_2 standards. The Coburn Road site had the highest annual average in Billings (.029 ppm) and the Laurel-BN site had the highest annual average in Laurel (.010 ppm). The Montana annual standard is set at .020 ppm.

The second objective (to validate a model) was perhaps simply and optimistically stated. It was not exactly clear in the stipulation what was meant by the word "model." However, as a first approach, the intent did seem to mean Gaussian plume dispersion models. In fact, emission and meteorological data was collected which would be input to such models. The Department endeavored to validate Gaussian plume dispersion models but the effort was unsuccessful and the models were invalidated (or disproved) for the Billings and Laurel areas.

Since Gaussian plume dispersion models were disproved for the area, the stipulation did seem to allow the Department to apply alternative methods (models) to determine source contribution. The Department used direction analysis and mass emissions to calculate source contribution. This was shown in the previous section.

Although the models were disproved for the Billings area, it should not be assumed that all modeling endeavors give poor results. Gaussian plume dispersion models are still the best tool available to show possible impacts by proposed sources. The Department feels that they should definitely be retained as part of the permitting process. The authors of the models maintain that they do not include calculations for the transitional phenomenon of fumigation or the breakup of inversions. It is no wonder that the models were unable to predict concentrations from the Billings and Laurel industries.

The Department notes: If the same sources existed on a flat terrain with the same set of emissions, then there probably wouldn't be any violations of the ambient standards. This is essentially what the models are predicting. Given the intervening terrain and meteorology, a situation creates itself whereby SO_2 concentrations build up or impact the ground and cause violation of standards.

In order to give more understanding of the inversion breakup phenomenon, Figure 76 shows a sequence of valley cross sections illustrating the breakup of a valley temperature inversion beginning at sunrise and ending at the time of inversion destruction. This figure is depictive of what happens in the Billings and Laurel areas during all parts of the year. (This figure is referenced to a paper written by C. David Whiteman and K. Jerry Allwine which is entitled " A New Pollutant Dispersion Model for Application in Mountain Valleys.") The inversion is destroyed by the upward growth from the ground of a convective boundary layer and the subsidence or sinking of the temperature inversion layer after sunrise.

The stipulation addressed the possibility of raising stack heights to control emissions or to lower air quality levels. Modeling assumptions also base their predictions on stack heights and plume rise. It is the Department's opinion that stack heights in Billings do little to control or lower ambient concentrations. For example, plume impaction by subarea C (Exxon and Montana Sulphur) is seen at the Lockwood Park site which is only a half a mile away. Also, the Montana Power Corette stack impacts the Coburn Road site which is about a mile away. Again, stack heights seem to do little to lower ambient concentrations in Billings and raising stack heights should not be an acceptable method for controlling SO_2 levels.

The signees of the stipulation were also interested in whether there were any areas that would show higher levels than those measured by the ambient monitors. This would have been accomplished by adding additional receptor locations in the models. Since the models did not work, the Department makes the decision based on weather patterns and observed ambient levels.

The Department feels that the Coburn Road site is probably the worst case site in the Billings and Laurel area. The Coburn Road site receives SO_2 emissions from both the NE and SW directions and also from above during inversion breakups. The Coburn Road site is also an elevated site (sits high on a ridge) and is at a height where buildups occur during calm weather conditions (close to the inversion level).

The Department wishes to point out that there are areas other than the immediate Billings-Laurel area that are affected by the emissions from the Billings and Laurel industries. It is the Department's judgement that the SO_2 may stretch along a line over the Yellowstone River to points as far away as Columbus to the SW and Pompey's Pillar to the NE. The concentrations judged at these distant locations could be as high as .005 ppm on an annual average.

The Department also feels that there are no significant SO_2 sources in the Billings area other than the industries that this report addresses. Montana Power, Conoco, Great Western, Exxon, Montana Sulphur and Cenex. There may be some small miscellaneous sources, but these would probably contribute less than a half of percent of all the emissions.

XXII. SUMMARY AND CONCLUSIONS

1. The ambient air quality data collected during the study year (October 1, 1981 to September 30, 1982) shows violations of state annual and twenty-four hour standards. There were no violations of any Federal standards.

2. The source contribution for the Coburn Road site (annual average equal to .029 ppm SO_2) is as follows:

Montana Power	31%
Conoco	14
Great Western	3
Exxon	30
Montana Sulphur	10
Cenex	12
	100%

3. The source contribution for the Laurel-BN site (annual average equal to .010 ppm SO_2) is as follows:

Montana Power	6%
Conoco	4
Great Western	1
Exxon	9
Montana Sulphur	3
Cenex	77
	100%

4. Gaussian plume models were proved invalid for the Billings and Laurel area and cannot be used to determine source contribution.

5. Federal annual SO_2 violations might occur if the Montana Power Corette plant ran for the whole year or if there were some increases in production at the oil refineries.

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